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(54) Title: METHOD AND APPARATUS FOR COMBINING TRANSPONDERS ON MULTIPLE SATELLITES INTO VIRTUAL CHANNELS

(57) Abstract

A satellite communications system provides an information channel between remotely located transmitters and receivers. A virtual satellite system provides the same service, but divides the signal either in power or in data content into subchannels such that any particular signal is conducted to the intended receiver via a plurality of traditional satellite channels. The receiving terminal (16) accepts the plurality of signals (26A, 26B, 26C, 26D) simultaneously from a possible plurality of satellites (14A, 14B, 14C, 14D), combining the subchannels comprising the virtual channel into the original signal content as if conducted via a single channel. The receiving antenna system (16) receives satellite subchannel signals (14A, 14B, 14C, 14D) from a plurality of directions using multiple antennas or a single antenna (30) with multi–direction capability. Prior to signal combining, the receiver (16) necessarily time–synchronizes the plurality of subchannels by introducing time delay in some channels before combining the subsignals into the original composite.

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METHOD AND APPARATUS FOR COMBINING TRANSPONDERS ON MULTIPLE SATELLITES INTO VIRTUAL CHANNELS

BACKGROUND OF THE INVENTION

5   The invention relates to satellite communications systems generally, and more particularly to satellite communication systems which divide the transmitted signal, either in power or in content, to be synchronized and recombined in the receiving terminal. This concept applies readily to broadcast applications, but it not so limited.

10   The satellite industry has experienced a progression of performance enhancements evidenced by increased transmit power capability of satellite transponders, improved low-noise amplifier (LNA) characteristics, and smaller receiving antennas. In satellite systems with a large number of receiving stations, it is particularly important to

15   reduce the cost of each receiving unit and to design a system with a small receiving antenna to meet installation and aesthetic requirements. The need for a small receiving antenna has motivated an increase in transponder power output in order to maintain an acceptable signal-to-noise ratio (SNR) with the smaller antenna. As

20   satellite users move from lower power transponders to higher power transponders, falling demand for the lower power transponders reduces the cost of their use. Receiving a signal from a lower power transponder with the smaller receiving antenna size produces a received power at the LNA too low to maintain SNR requirements.

25   The present invention permits the receiver to combine received signals from a plurality of transponders, possibly located on a plurality of satellites to enable again the use of lower power transponders, but with small receiving terminal antennas.

SUMMARY OF THE INVENTION

A satellite communications system includes a transmitting station that directs information-carrying signals toward an orbiting satellite, which receives the signals and in turn retransmits the signals on a different frequency band toward a plurality of receiving terminals. The satellite contains a transponder which receives signals as a broad band of frequencies and retransmits them on another set of frequencies of equal bandwidth but shifted to another location in the spectrum.

The present invention has as its object a satellite communications system including a transmitting facility that divides the signal into a plurality of subchannels directed toward a plurality of transponders located on one or more satellites and a receiving terminal that receives the subchannels, time-synchronizes the subchannels, and combines them into a faithful replica of the original composite signal. The division of the signal into subchannels is carried out by one of two methods. In a first division method, the source signal is replicated across the plurality of transponders. Hereinafter the first division method is referred to as power-division. In a second division method, the content of the source signal is represented by a set of distinct subsignals, each of which subsignals contains less information as the original signal, but said distinct subsignals can be conveniently recombined in the receiver to reconstruct the original signal satisfactorily. Hereinafter this second division method is referred to as content-division.

In a system using power-division to create subchannels, the originating transmitter directs more than one identical signal to a plurality of transponders, possibly located on a plurality of satellites. In said system, transponders retransmit and the receiving antenna system conducts all of the aforementioned signals into the receiving system. The receiving terminal provides means of time-synchronizing

the plurality of received signals, adjusts the relative power level of the plurality of received signals to be approximately equal, and combines the signals into a composite via a signal adding process. Each of the signals added contains both an information component and a random

5   noise component, such noise having been introduced primarily in the first amplifier of the receiver, typically a low-noise block converter (LNB). Those skilled in the art know that the information component of each signal will be statistically correlated, but the noise components will be statistically uncorrelated, both to each other and to the

10   information component. Thus the information components will add linearly into the composite signal, that is in proportion to their number. The power in the information component of the composite signal will then be in proportion to the square of the number of received signals being added together. In contrast, the power in the noise component

15   of the composite signal will be in proportion to the number of received signals added together. Thus the SNR of the composite signal is improved over the SNR of the individual subchannel signals by a factor of N in power, where N is the number of channels added together to form the composite signal. The foregoing discussion

20   assumes that the signal levels and noise levels in each of the subchannel signals is identical.

In a real system, transmission characteristics will vary slightly between subchannels, signal and noise levels being slightly different between subchannels, resulting in an SNR improvement ratio

25   somewhat less than the factor of N described above. In any case, the receiver may require automatic means of adjusting the power of each of the signals to be added at the combining point so as to be approximately equal to each other in level.

In a system using content-division to create subchannels, the

30   originating transmitter directs distinct subsignals toward the plurality of transponders, the subsignals being created in such a way as to permit

convenient reconstruction of the original signal at the receiving terminal. In an exemplary analog system, the original signal can be divided into subband signals using a filter-bank process. If the filters used satisfy quadrature-mirror properties, the subsignals can be added

5   directly to reproduce the original signal without phase distortion at the boundary frequencies. If the analog signal contains a strong periodic timing component (as does a television signal), this periodic timing component can be separated from the remainder of the signal before dividing the signal into subband components. Said timing component

10   could then be added back to each of the subband components to produce subchannel signals with different frequency components, but common timing information. This strategy naturally provides timing information useful to facilitate the necessary time-resynchronizing process in the receiver.

15   As above, in a system using content-division to create subchannels, the originating transmitter directs distinct subsignals toward the plurality of transponders, the subsignals being created in such a way as to permit convenient reconstruction of the original signal at the receiving terminal. In an exemplary digital system, the

20   original binary signal can be divided into subchannel digital signals, each of which has a bit rate less than the original digital signal. The original digital signal can be divided into subchannel digital signals in any number of ways. Two simple exemplary digital subchannel strategies are as follows. A first exemplary digital subchannel strategy

25   is to direct each successive bit into each subchannel sequentially. A second exemplary digital subchannel strategy is to direct each fixed-size block of bits in the original signal to each successive subchannel sequentially. This second exemplary strategy fits well with digital source signals that are organized in a fixed-block-size structure in the

30   original signal.

In the case that a plurality of satellites is used to conduct a set of subchannels from a transmitting station to a given receiving terminal, each subchannel will generally experience a different propagation delay. The instant invention provides means to

5   determine the amount of time to delay each subchannel in order to combine them synchronously. The delay required for each received subchannel will in the general case differ. The present invention provides additional means to implement the aforedetermined delay for each subchannel independently.

10   The receiving terminal system, when activated for a particular virtual channel, determines the relative delay between the subchannel signals arriving at the receiver. This could be accomplished by correlating the subchannel signals with each other at all possible delays expected in a particular implementation of the system. As this

15   process is very time consuming and source signal dependent, it is therefore subject to false synchronization and possible failure to synchronize at all, particularly if the source signal does not contain enough timing information. The present invention solves this problem by transmitting a timing signal along with the original signal. Said

20   timing signal arrives at the receiving terminal via a plurality of propagation paths, each experiencing a different delay. The timing signal is added to the virtual satellite system in such a way so as to be separable from the original signal on each subchannel. The receiving terminal then correlates timing signals arriving on different

25   subchannels to determine the amount of relative propagation delay. All subchannel signals contain common timing information to facilitate the correlation process. This guarantees that the subchannels can be processed and compared in a known way to determine relative propagation delay.

30   The timing signal can be added to the virtual satellite channel using one of two exemplary methods, but the instant invention is not

so limited. A first exemplary method requires that a narrow bandwidth signal be transmitted across each satellite in the virtual channel. The narrow band signal requires a small allocation of the available spectrum, but provides a dedicated timing signal on each satellite

5   actively carrying virtual satellite channels. The narrow band timing signal provides propagation delay information to virtual channel receiving terminals having one or more subchannels on the satellite. The timing signal could consist of one or more of the following exemplary signals, but the instant invention is not so limited. A first

10   exemplary signal is a carrier modulated digitally by a binary pseudorandom noise sequence. A second exemplary signal is a periodic pulse. The pulse could be time-dispersed prior to transmission to create a signal with improved peak to average waveform properties. The receiving terminal in this example would

15   reverse the time-dispersal process to recover a narrow-time pulse. The time period of either exemplary signal above described, after which the signal repeats, would be longer than twice the greatest expected delay difference between subchannels, thus facilitating unambiguous determination of propagation delay.

20   A second exemplary method of incorporating a timing signal in the virtual satellite system consists of adding a spread spectrum component to each of the information-bearing subchannels in the system, and within the bandwidth of each subchannel. The magnitude of the spread spectrum timing component is much lower than the

25   information signal so as not to reduce the performance of the normal receiver demodulation process. The spread spectrum signal is then despread in the receiving terminal, thereby increasing its magnitude above that of the information content. The increase in signal level is proportional to the processing gain. This process facilitates delay

30   synchronization in the receiving terminal and has two advantages. A first advantage is that the second exemplary method does not

increase the bandwidth requirements of the virtual channel to accommodate a timing signal. A second advantage is that the full bandwidth of the information channel is available to the timing signal resulting in high resolution relative delay estimation.

DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic and block diagram illustrating the present invention.

Fig. 2 is a schematic and circuit block diagram of one embodiment of the present invention.

Fig. 3 is a schematic and circuit block diagram of another embodiment of the present invention.

Fig. 4 is a schematic and circuit block diagram of another embodiment of the present invention.

DESCRIPTION OF THE INVENTION

Referring now to the drawings in which like reference numerals indicate like or corresponding elements over the several views, FIG. **1** shows an overview of the satellite communications system consisting of subsystems **12**, **10**, **16**. Original signal **22** feeds subchannel divider **24** which separates the signal into a plurality of numbered subsignals. The exemplary system of FIG. **1** shows the number of subsignals to be four, but the present invention is not so limited. Subchannel divider **24** creates the subsignals by dividing original signal **22** employing one of two methods. A first method divides the signal on the basis of power. In this first method all the subchannel signals emerging from subchannel divider **24** are identical. A second method divides the signal on the basis of content. In this second method, each subchannel signal carries at least some information that is not carried by the other subchannels. The information content may be mutually exclusive or may overlap between subchannels, but in any case the

subchannel signals under the second divider method are not identical as in the first method. Each subchannel signal feeds an uplink transmitter **26a-26d**, each of which uplink transmitters feeds a separate antenna **28a-28d**, directing radio frequency energy toward a

5   plurality of orbiting satellites **14a-14d** via propagation paths **18a-18d**. Uplink transmitters **26a-26d** add timing signal **23** to the signal to be transmitted either on a separate frequency allocation or in the bandwidth of the information-bearing carrier.

The exemplary system of FIG. **1** shows the number of satellites

10   used by the system to be four, but the instant invention is not so limited. Each satellite **14a-14d** receives a band of frequencies, amplifies the signals received in that band, and retransmits the band at a different location in the spectrum. Each of said satellites has a transmitting antenna pattern that includes receiving terminal system

15   **16**. Propagation paths **20a-20d** from each satellite **14a-14d** to representative receiving terminal **16** carry radio frequency energy from satellites **14a-14d** to the receiving terminal system **16**. It should be understood that although FIG. **1** depicts each uplink signal being carried by a different satellite, the present invention is not so limited.

20   For example, transponders of satellites **14a**, **14b** could be collocated on the same satellite. In this case, uplink transmitters **26a**, **26b** and uplink antenna systems **28a**, **28b** could be combined, in addition to satellites **14a**, **14b** representing the same satellite. Propagation paths **18a**, **20a**, **18b**, **20b** in this case would be combined into single uplink

25   and downlink propagation paths. Receiving terminal system **16** incorporates one of two antenna methods. A first method includes a plurality of antenna components to receive the plurality of satellite signals **20a-20d**. A second method incorporates a multiple beam antenna. The exemplary system of FIG. **1** uses multiple beam

30   antenna **30**, but the present invention is not so limited. In either of the aforementioned receiving terminal antenna methods, the antenna

subsystem produces a plurality of output signals corresponding to the subchannel signals emerging from subchannel divider **24** in uplink system **12**. In the exemplary system of FIG. **1**, each of the numbered signals emerging from multiple beam antenna **30** correspond to

5 similarly numbered signals emitted by subchannel divider **24**. This signal identity remains true whether satellites **14a**, **14b** of FIG. **1** are distinct or represent the same satellite as indicated in the foregoing description. The subchannel signals emitted by multiple beam antenna **30** feed a plurality of tuners **32** which then drive a plurality of

10 demodulators **34**. A signal emerging from one of the demodulators **34** then represents a version of the corresponding output of subchannel divider **24**, but delayed in time in proportion to the sum of the lengths of the corresponding uplink and downlink propagation paths **18** and **20**. In receiving terminal **16**, delay component **36** further delays first-

15 arriving signals such that all the subchannel components arrive at subchannel combiner **38** at nearly the same time. Said combiner **38** produces a reconstruction **40** of original signal **22**. The method used in subchannel combiner **38** is consistent with and corresponds to the method used to divide original signal **22** in subchannel divider **24**.

20 (DIGITAL CONTENT-DIVISION)

The instant invention uses one of three methods to affect the dividing and combining operations of subchannel divider **24** and subchannel combiner **40**. In each of said methods, subchannel divider **24** of FIG. **1** feeds a plurality of uplink transmitters **26a-28b**, but the

25 signals emerging from subchannel divider **24** are different in nature depending of the dividing and combining method used. In a first dividing and combining method, original signal **22** is digital. In said first method, subchannel divider **24** divides said digital signal into lower data rate subchannel signals with binary content that contains at

30 least some mutually exclusive information. The division could be on a sequential bit-by-bit basis, could be on a sequential frame-by-frame

basis, and may or may not relate to possible framing in the original digital signal. The exemplary receiving terminal **16** of FIG. **2** depicts a two-subchannel digital receiving system where the radio frequency carriers feeding the demodulators **36a** and **36b** are quaternary phase shift keying (QPSK) modulated signals, but the present invention is not so limited. Said figure further indicates the use of a multiple beam antenna **30**, but the present invention is not so limited. Referring again to FIG. **2**, multiple beam antenna **30** emits first and second signals into first and second tuners **32a** and **32b**. Each tuner shifts a band of higher frequencies to a band of lower frequencies of equal bandwidth such that receiver controller **42** sets the center frequency of the higher band, but the lower band is fixed. Tuners **32a**, **32b** emit QPSK modulated signals at a frequency that the QPSK demodulators **36a**, **36b** expect to receive. As there are two subchannels in the example of FIG. **2**, the data rate of the binary information contained in these QPSK signals is approximately half the data rate of original signal **22**. The respective outputs of QPSK demodulators **36a**, **36b** emit signals to bit detectors **38a**, **38b** which in turn produce streams of binary data corresponding to the subchannel division in uplink system **12**. Delay operators synchronize the data streams by introducing delay in the first-arriving binary stream such that there is a minimum of relative delay between the respective delay operator outputs. Digital content combiner **48** reverses the content division process of subchannel divider **24** so as to produce at its output a faithful delayed replica **50** of original digital signal **22**. Receiver controller **42** of FIG. **2** responds to user input (not depicted) to select the transponders **14** to combine, subsequently emitting control signals to multiple beam antenna **30** to direct its antenna patterns toward the satellites containing selected transponders **14**. Receiver controller **42** also selects each tuner frequency consistent with the signals emitted from the selected transponder. Receiver controller **42** further processes

information from timing signal correlator **44** to determine the correct
setting of delays **40a**, **40b**. Timing signal correlator **44** receives and
time-correlates tuner outputs **34**. For a system with more than two
subchannels, correlator **44** processes tuner outputs in pairs to
determine relative delay between subchannels. Nonvolatile memory
46 contains parameters regarding the user-selected transponders to
enable the correct setting of multiple beam antenna **30** and tuners **32**.

(DIGITAL POWER-DIVISION)

The instant invention can use a second method for transporting
a digital signal across a virtual satellite channel. Referring to FIG. **3**
which depicts an example of said second method which combines
delayed demodulator outputs from identical subchannels as described
previously as power combining. Under the direction of receiver
controller **42**, multiple beam antenna **30** emits signals to tuners **32a**,
32b which translate variable transponder bands into a fixed band of
frequencies expected by the QPSK demodulators **54**. FIG. **3** depicts a
receiving terminal using a multiple beam antenna, but the present
invention is not so limited. FIG. **3** further depicts a receiving terminal
with two subchannels, but the instant invention is not limited to two
subchannels. The figure in addition shows the use of a QPSK
modulation scheme, but the instant invention is not so limited.
Subchannel signals **52** emitted by tuners **32** contain identical digital
information transmitted at the full rate of original signal **22**. QPSK
demodulators **54** produce soft decision outputs I_A and Q_A for each
subchannel. Since the total propagation delay for each subchannel is
in general different, first-arriving soft decisions must be delayed in time
by an amount such that soft decisions emitted by delays **56** emerge
with nearly zero relative delay between subchannels. Delays **56**
digitize the analog soft decisions produced by demodulators **54**,
placing digitized results in a first-in first-out (FIFO) buffer. Receiver
controller **42** controls the amount of time delay in delays **56** with input

from timing signal processor **44** and digital correlator **58**. Timing signal processor **44** analyzes input from tuner outputs **52** to determine the relative time delay between subchannels. For systems using more than two subchannels, the timing signal processor would process

5   subchannel tuner outputs in pairs. Since the subchannels of FIG. **3** result from use of an uplink system **12** using power division, delay outputs I_B and Q_B from delays **56a**, **56b** are correlated. This enables digital correlator **58** to compare digitized soft decisions between subchannels and provide additional information to receiver controller

10   **42** about relative subchannel delay at the bit level. Digital power combiner **66** processes synchronized I and Q soft decisions from all subchannels to produce a single I and Q decision **68** for every set of soft decisions presented. For the case of QPSK modulation, each final decision from combiner **66** produces two bits in digital output **68**.

15   (ANALOG DIVISION)

A third method for dividing and combining the original signal address the case that original signal **22** is analog in nature. Referring to FIG. **4**, receiver controller **42** directs multiple beam antenna **30** to point to selected transponder signals and directs tuners **32a**, **32b** to

20   translate said transponder frequencies to a fixed band of frequencies expected by demodulators **70a**, **70b**. The exemplary system of FIG. **4** divides the signal into two subchannels, but the instant invention is not so limited. Demodulators **70a**, **70b** produce analog outputs signals which are faithful replicas of the subchannel signals produced by

25   subchannel divider **24** in the uplink system **12**. Said analog signal outputs in general experience relative delay due to differing lengths of total propagation paths when using transponders on different satellites. Under direction of receiver controller **42**, analog delays **72** add delay to first-arriving subchannel signals so as to create outputs of analog

30   delays **72** which arrive at analog combiner **80** with near zero relative delay. Analog delays **72** consist of a high quality analog-to-digital

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converter (A/D), a FIFO buffer, and a digital-to-analog (D/A) converter. Each delays **72** creates a time delay in proportion the instant size of the FIFO buffer contained therein. Delays **72** present output signals to analog combiner **80** which represent faithful replicas of the subchannel

5   signals produced by subchannel divider **24** in the uplink system **12**. These signals differ outputs of demodulators **70** in that they are now time synchronized. FIG. **4** represents both signal division strategies, power-division and content-division. In the first case of power-divided subchannel signals, inputs to analog combiner **80** represent identical

10   signals, differing only in distortion and noise added by satellite transport. In a second case, time-synchronized content-divided subchannel signals arrive at analog combiner **80**. Analog combiner **80** creates output **82** most likely by a simple addition process, but is not so limited. In addition to producing combined output signal **82**, analog

15   combiner **80** optionally provides a measure of time synchronization to receiver controller **42** to improve the accuracy of time alignment by controller **42**. As in first and second digital divider-combiner methods, timing signal correlator **44** provides relative subchannel delay information to receiver controller **42**, which together with further

20   optional delay information from analog combiner **80** provides receiver controller **80** with a basis to create estimates of relative delay between subchannels which in turn affects the setting of delays **72**.

(TIMING)

In first, second, and third divider-combiner methods, tuners **32**

25   provide information to timing signal correlator **44** using one of two timing methods. In a first timing method, receiver controller **42** adjusts tuners **32** to receive timing signal **23** placed on all satellites with transponders used by the virtual satellite system. In this first method, tuner adjustment is necessary as the timing signals are placed at a

30   frequency assignment separate form the information-bearing transponder signal. This out-of-band timing signal may be narrow-

band in nature so as to conserve limited bandwidth on the satellite and reduce system cost. In general, timing signal **23** is unrelated to the information-bearing transponder signal in either information content, modulation strategy, or data rate or frame rate in the case of digital

5   transmission, but the present invention is not so limited. The timing signal utilizes allocated bandwidth to enhance the resolution of relative subchannel delay estimation. Possibilities for the timing signals include pseudorandom noise, tone ranging, and time-dispersed pulse, but the instant invention is not so limited. A good timing signal must

10   have a strong sharp cross-correlation with a time-shifted version of itself and have minimum spurious correlations. The instant invention includes two timing signal processor methods. In a first timing processor method, timing signal correlator **44** correlates output signals from tuners **32** at various relative delays until an acceptable correlation

15   occurs indicating that the relative delay between the subchannels has been reproduced in timing correlator **44**. Receiver controller **42** then sets analog delays **72** in accord with this measured relative delay to synchronize inputs to analog combiner **80**. In the case that there are more than two subchannels in the virtual satellite channel, timing

20   signal processor **44** compares subchannel signals pairwise. In a second timing processor method, timing signal correlator **44** correlates the output from each tuner **32** with a stored version of the known timing signal, or by processing the recovered timing signal through a process that will produce a periodic output in response to the timing

25   signal. One example of such a process is a matched filter, but the present invention is not so limited. Once the delays **40, 56, 72** are adjusted to remove relative subchannel delay, tuners **32** are set to conduct the selected information-bearing transponder signals to the respective demodulators in FIG. **1**, FIG. **2**, FIG. **3**.

30   In a second timing method, the timing signal is as wide in bandwidth as the information-bearing transponder and resides in

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exactly the same bandwidth. In order to prevent distortion of the information signal, the timing signal is greatly attenuated. In order to recover the attenuated timing signal, timing signal correlator **44** first processes the tuner outputs through a linear system that creates a

5   large processing gain to amplify the expected timing signal above the output created by the presence of the uncorrelated information-bearing carrier. The instant invention may use one of three exemplary processes to recover a low-level in-band timing signal, but the present invention is not so limited. In a first exemplary process the timing

10   signal is a time-dispersed pulse with precise time dispersion introduced by a surface acoustic wave (SAW) filter in timing signal generator **23**. A matching SAW filter in receiving terminal **16** performs the inverse of the dispersion process, thus recovering the primary timing signal which is a periodic narrow-time pulse. In a second

15   exemplary process, the timing signal is pseudorandom noise. Timing signal processor **44** then applies spread spectrum techniques to recover the timing of the low-level in-band timing signal. Upon timing signal acquisition, the correlated timing signal will experience a large process gain, but the uncorrelated information carrier will remain at the

20   same relative level. This enables timing signal processor **44** to establish relative delay between subchannels, reporting results to receiver controller **42**. A third exemplary timing process uses a multiple tone signal to establish timing. The sine waves selected are harmonically related in such a way as to create a signal with a

25   relatively long period, but giving good time resolution with the presence of some high frequencies. A linear filter at the selected frequencies recovers the timing signal in favor of the information carrier. Timing signal processor **44** then analyzes filtered timing signals to establish relative time delay between subchannels.

30   In the case of the digital content-division receiver of FIG. 2, there is typically no correlation between the subchannels to provide

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feedback as to the accuracy of the delay settings of delays **40**. This is a feedforward control system. Feedback is possible however in the exemplary systems of FIG. **3**, FIG. **4**. Outputs from delays **56** in the digital power-division receiver of FIG. **3** are highly correlated. If the

5   delay setting is slightly in error, a local digital correlation reveals the necessary small correction. Outputs from delays **72** in the analog receiver of FIG. **4** are correlated to some extent depending on the nature of the analog division and the instant properties of the analog content. This provides optional feedback to receiver controller **42** to

10   affect local timing corrections.

While several particular forms and variations thereof have been illustrated and described, it will be apparent that various modifications can be made without departing from the spirit and scope of the invention. Accordingly it is not intended that the invention be limited,

15   except by the appended claims.

I claim:

1. A satellite communications system which provides an enhanced digital communication channel, the satellite communications system comprising:

5   a multi-channel uplink system dividing the original signal into a
                   plurality of subchannels and adding a common timing
                   signal to each subchannel, the multi-channel uplink
                   system comprising:

           a subchannel divider for transforming the original digital signal
10   into a plurality of digital subchannels such that each
                   digital subchannel signal contains at least some
                   information unique to that subchannel and also such that
                   the bit rate of each digital subchannel signal is lower than
                   the bit rate of the original digital signal;

15   a timing generator creating a periodic signal,

           signal combining means coupled to the timing generator output
                   and the subchannel divider output associated with each
                   subchannel for adding the common timing signal to each
                   subchannel information signal and within the bandwidth
20   of each subchannel information signal such that no
                   additional bandwidth allocation is required to transmit the
                   timing information signal;

           upconverting means coupled to the signal combining means
                   output associated with each subchannel for translating
25   the frequency of the timing-added subchannel signal to
                   the frequency of the selected satellite transponder;

           amplifier means coupled to the upconverting means output
                   associated with each subchannel for increasing the
                   power of the translated, timing-added subchannel signal;
30   and

antenna means coupled to the amplifier means output
associated with each subchannel directing a radio
frequency wave toward the receiving antenna of the
satellite containing the transponder selected for the
5   associated subchannel; and

a receiving terminal system collecting signals from a plurality of
selected satellite transponders and creating a delayed
reconstruction of the original signal, the receiving terminal
system comprising:

10   a multiple beam antenna simultaneously receiving signals from
the plurality of transponders and presenting each of said
signals on a separate output port;

a tuner coupled to each multiple beam antenna output port for
translating the frequency of each received signal to a
15   fixed intermediate frequency;

a demodulator coupled to each tuner output for demodulating
tuner output and creating a bit stream corresponding to
the information content of the associated subchannel;

delay means coupled to each demodulator output for delaying
20   first-arriving subchannel signals such that outputs of the
plurality of delay means are synchronized in time;

a digital combiner coupled to the output of the plurality of delay
means for combining the information in each of the
subchannels into a delayed reconstruction of the original
25   digital signal;

a timing signal correlator coupled to each tuner output for
measuring the relative delay between arriving subchannel
signals;

a nonvolatile memory for storing information about the
30   frequency and propagation delay properties of the virtual
channels to be selected; and

a controller coupled to the multiple beam antenna, the plurality
of tuners, the plurality of delay means, the timing signal
correlator, and the nonvolatile memory for receiving
signals from the timing signal correlator and the
nonvolatile memory and issuing control signals to the
multiple beam antenna setting beam direction and
polarization, control signals to the tuners to set
subchannel receive frequencies, and control signals to
the plurality of delay means to synchronize delay means
outputs.

2. The satellite communications system of claim 1 wherein at
least some of the transponders associated with the plurality of
subchannels are located on the same satellite.

3. The satellite communications system of claim 1 wherein the
multiple beam antenna is replaced with multiple independent single
beam antennas.

4. The satellite communications system of claim 2 wherein the
multiple beam antenna is replaced with multiple independent single
beam antennas.

5. The satellite communications system of claim 1 wherein the
timing signal associated with any particular subchannel is transmitted
in a separate frequency allocation but on the same satellite as the
information-bearing carrier, requiring the controller to firstly direct the
tuners to receive the frequency-separated timing signal to measure
relative propagation delay of the subchannels, secondly set the
amount of delay in the plurality of delay means in accord with the
relative propagation delays measured in the first step, and thirdly

redirect the tuners to receive the associated information-bearing subchannels.

6. The satellite communications system of claim 5 wherein at least some of the transponders associated with the plurality of subchannels are located on the same satellite.

7. The satellite communications system of claim 5 wherein the multiple beam antenna is replaced with multiple independent single beam antennas.

8. The satellite communications system of claim 6 wherein the multiple beam antenna is replaced with multiple independent single beam antennas.

9. A satellite communications system which provides an enhanced digital communication channel, the satellite communications system comprising:

a multi-channel uplink system dividing the original signal into a plurality of subchannels and adding a common timing signal to each subchannel, the multi-channel uplink system comprising:

a subchannel divider for transforming the original digital signal into a plurality of digital subchannels such that each digital subchannel signal carries identical information at the same bit rate as the original digital signal;

a timing generator creating a periodic signal,

signal combining means coupled to the timing generator output and the subchannel divider output associated with each subchannel for adding the common timing signal to each subchannel information signal and within the bandwidth

of each subchannel information signal such that no additional bandwidth allocation is required to transmit the timing information signal;

upconverting means coupled to the signal combining means output associated with each subchannel for translating the frequency of the timing-added subchannel signal to the frequency of the selected satellite transponder;

amplifier means coupled to the upconverting means output associated with each subchannel for increasing the power of the translated, timing-added subchannel signal; and

antenna means coupled to the amplifier means output associated with each subchannel directing a radio frequency wave toward the receiving antenna of the satellite containing the transponder selected for the associated subchannel; and

a receiving terminal system collecting signals from a plurality of selected satellite transponders and creating a delayed reconstruction of the original signal, the receiving terminal system comprising:

a multiple beam antenna simultaneously receiving signals from the plurality of transponders and presenting each of said signals on a separate output port;

a tuner coupled to each multiple beam antenna output port for translating the frequency of each received signal to a fixed intermediate frequency;

a demodulator coupled to each tuner output for demodulating tuner output and creating a stream of soft decisions in the form of digitized decision-confidence-values corresponding to the associated subchannel;

delay means coupled to each demodulator output for delaying
first-arriving subchannel signals such that soft decision
outputs of the plurality of delay means are synchronized
in time;

5   a digital combiner coupled to the output of the plurality of delay
means for combining soft decision from all subchannels
received into a delayed reconstruction of the original
digital signal;

a timing signal correlator coupled to each tuner output for

10   measuring the relative delay between arriving subchannel
signals;

a digital correlator coupled to the delay means outputs for
providing an additional measure of the relative delay
between channels;

15   a nonvolatile memory for storing information about the
frequency and propagation delay properties of the virtual
channels to be selected; and

a controller coupled to the multiple beam antenna, the plurality
of tuners, the plurality of delay means, the timing signal

20   correlator, the digital correlator, and the nonvolatile
memory for receiving signals from the timing signal
correlator and the nonvolatile memory and issuing control
signals to the multiple beam antenna setting beam
direction and polarization, control signals to the tuners to

25   set subchannel receive frequencies, and control signals
to the plurality of delay means to synchronize delay
means outputs.

10. The satellite communications system of claim 9 wherein
there is no digital correlator.

11. The satellite communications system of claim 9 wherein at least some of the transponders associated with the plurality of subchannels are located on the same satellite.

12. The satellite communications system of claim 9 wherein the multiple beam antenna is replaced with multiple independent single beam antennas.

13. The satellite communications system of claim 11 wherein the multiple beam antenna is replaced with multiple independent single beam antennas.

14. The satellite communications system of claim 9 wherein the timing signal associated with any particular subchannel is transmitted in a separate frequency allocation but on the same satellite as the information-bearing carrier, requiring the controller to firstly direct the tuners to receive the frequency-separated timing signal to measure relative propagation delay of the subchannels, secondly set the amount of delay in the plurality of delay means in accord with the relative propagation delays measured in the first step, and thirdly redirect the tuners to receive the associated information-bearing subchannels.

15. The satellite communications system of claim 14 wherein at least some of the transponders associated with the plurality of subchannels are located on the same satellite.

16. The satellite communications system of claim 14 wherein the multiple beam antenna is replaced with multiple independent single beam antennas.

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17. The satellite communications system of claim 15 wherein the multiple beam antenna is replaced with multiple independent single beam antennas.

18. A satellite communications system which provides an enhanced analog communication channel, the satellite communications system comprising:

a multi-channel uplink system dividing the original signal into a plurality of subchannels and adding a common timing signal to each subchannel, the multi-channel uplink system comprising:

a subchannel divider for transforming the original analog signal into a plurality of analog subchannels such that each subchannel signal contains at least some information unique to that subchannel;

a timing generator creating a periodic signal,

signal combining means coupled to the timing generator output and the subchannel divider output associated with each subchannel for adding the common timing signal to each subchannel information signal and within the bandwidth of each subchannel information signal such that no additional bandwidth allocation is required to transmit the timing information signal;

upconverting means coupled to the signal combining means output associated with each subchannel for translating the frequency of the timing-added subchannel signal to the frequency of the selected satellite transponder;

amplifier means coupled to the upconverting means output associated with each subchannel for increasing the power of the translated, timing-added subchannel signal; and

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antenna means coupled to the amplifier means output
associated with each subchannel directing a radio
frequency wave toward the receiving antenna of the
satellite containing the transponder selected for the

5   associated subchannel; and

a receiving terminal system collecting signals from a plurality of
selected satellite transponders and creating a delayed
reconstruction of the original signal, the receiving terminal
system comprising:

10   a multiple beam antenna simultaneously receiving signals from
the plurality of transponders and presenting each of said
signals on a separate output port;

a tuner coupled to each multiple beam antenna output port for
translating the frequency of each received signal to a

15   fixed intermediate frequency;

a demodulator coupled to each tuner output for demodulating
tuner output and creating an analog signal corresponding
to the information content of the associated subchannel;

delay means coupled to each demodulator output for delaying

20   first-arriving subchannel signals such that outputs of the
plurality of delay means are synchronized in time;

an analog combiner coupled to the output of the plurality of
delay means for combining the information in each of the
subchannels into a delayed reconstruction of the original

25   analog signal;

a timing signal correlator coupled to each tuner output for
measuring the relative delay between arriving subchannel
signals;

a nonvolatile memory for storing information about the

30   frequency and propagation delay properties of the virtual
channels to be selected; and

a controller coupled to the multiple beam antenna, the plurality
of tuners, the plurality of delay means, the timing signal
correlator, and the nonvolatile memory for receiving
signals from the timing signal correlator and the
nonvolatile memory and issuing control signals to the
multiple beam antenna setting beam direction and
polarization, control signals to the tuners to set
subchannel receive frequencies, and control signals to
the plurality of delay means to synchronize delay means
outputs.

19. The satellite communications system of claim 18 wherein
the analog combiner provides additional relative subchannel delay
information to the controller.

20. The satellite communications system of claim 18 wherein at
least some of the transponders associated with the plurality of
subchannels are located on the same satellite.

21. The satellite communications system of claim 18 wherein
the multiple beam antenna is replaced with multiple independent single
beam antennas.

22. The satellite communications system of claim 20 wherein
the multiple beam antenna is replaced with multiple independent single
beam antennas.

23. The satellite communications system of claim 18 wherein
the timing signal associated with any particular subchannel is
transmitted in a separate frequency allocation but on the same satellite
as the information-bearing carrier, requiring the controller to firstly

direct the tuners to receive the frequency-separated timing signal to measure relative propagation delay of the subchannels, secondly set the amount of delay in the plurality of delay means in accord with the relative propagation delays measured in the first step, and thirdly

5   redirect the tuners to receive the associated information-bearing subchannels.

24. The satellite communications system of claim 23 wherein at least some of the transponders associated with the plurality of subchannels are located on the same satellite.

10   25. The satellite communications system of claim 23 wherein the multiple beam antenna is replaced with multiple independent single beam antennas.

26. The satellite communications system of claim 24 wherein the multiple beam antenna is replaced with multiple independent single
15   beam antennas.

27. The satellite communications system of claim 18 wherein the plurality of subchannels contain identical information, the associated carriers being modulated identically.

28. The satellite communications system of claim 27 wherein
20   the analog combiner provides additional relative subchannel delay information to the controller.

29. The satellite communications system of claim 27 wherein at least some of the transponders associated with the plurality of subchannels are located on the same satellite.

30. The satellite communications system of claim 27 wherein the multiple beam antenna is replaced with multiple independent single beam antennas.

31. The satellite communications system of claim 29 wherein the multiple beam antenna is replaced with multiple independent single beam antennas.

32. The satellite communications system of claim 27 wherein the timing signal associated with any particular subchannel is transmitted in a separate frequency allocation but on the same satellite as the information-bearing carrier, requiring the controller to firstly direct the tuners to receive the frequency-separated timing signal to measure relative propagation delay of the subchannels, secondly set the amount of delay in the plurality of delay means in accord with the relative propagation delays measured in the first step, and thirdly redirect the tuners to receive the associated information-bearing subchannels.

33. The satellite communications system of claim 32 wherein at least some of the transponders associated with the plurality of subchannels are located on the same satellite.

34. The satellite communications system of claim 32 wherein the multiple beam antenna is replaced with multiple independent single beam antennas.

35. The satellite communications system of claim 33 wherein the multiple beam antenna is replaced with multiple independent single beam antennas.
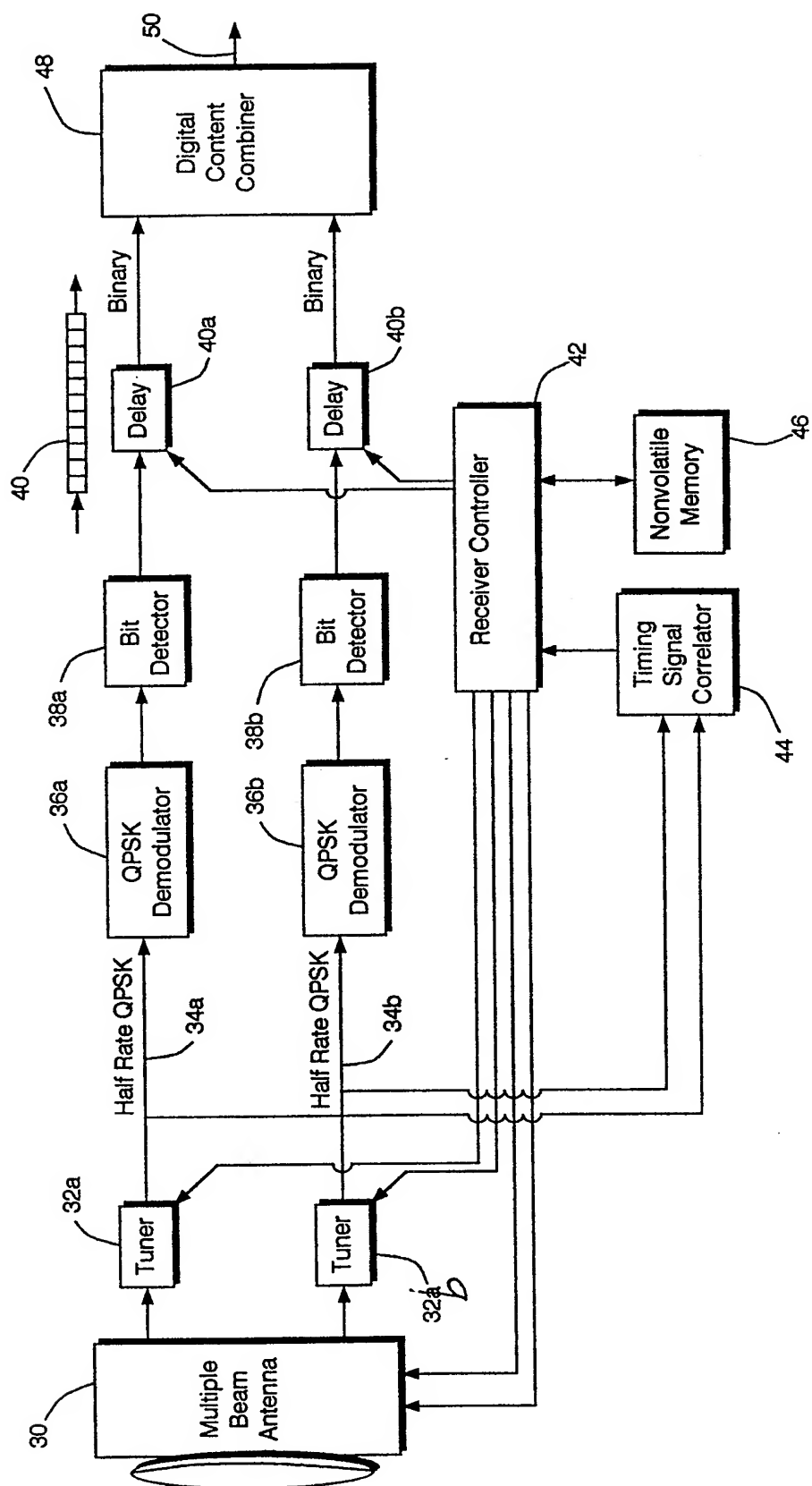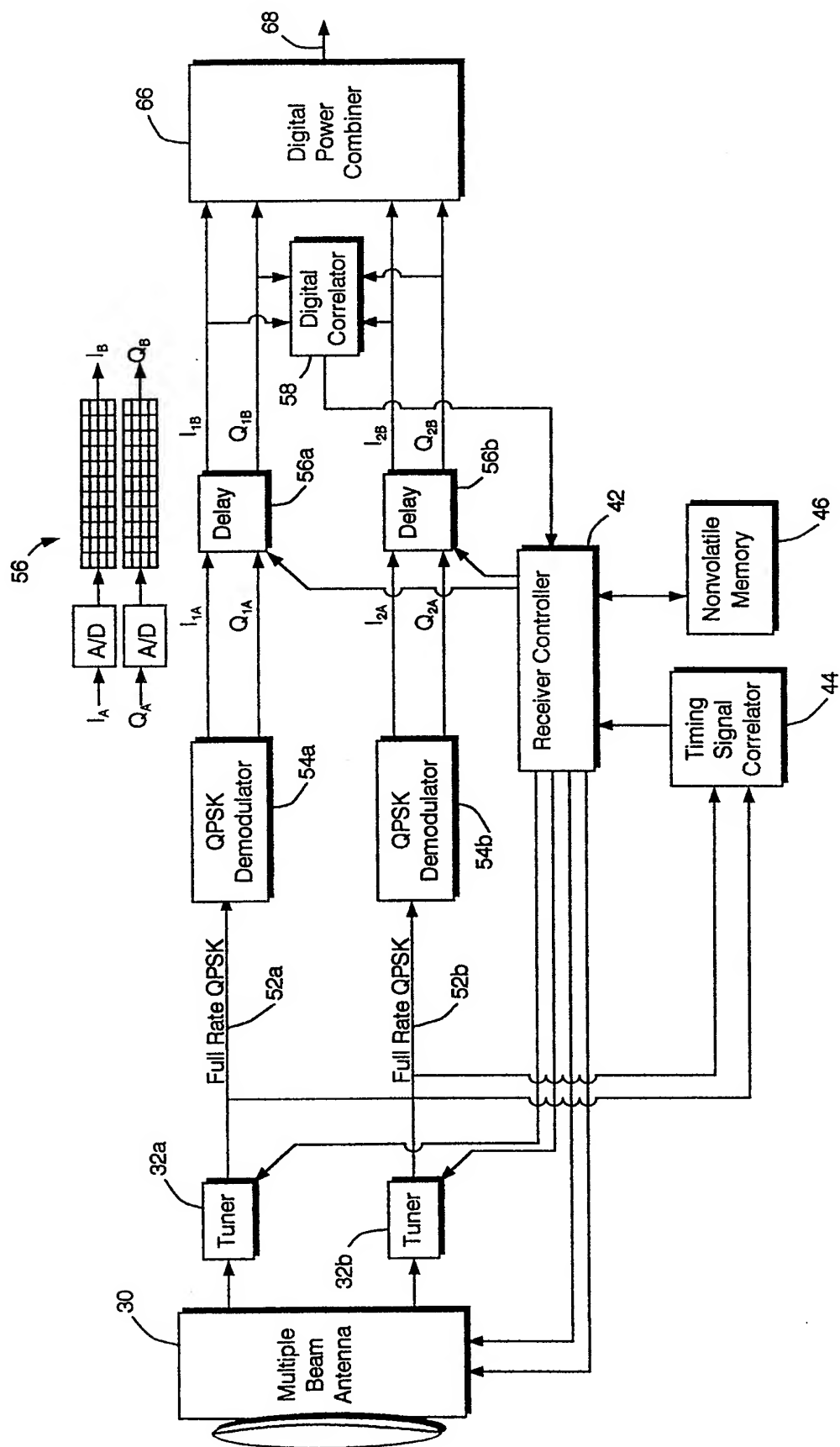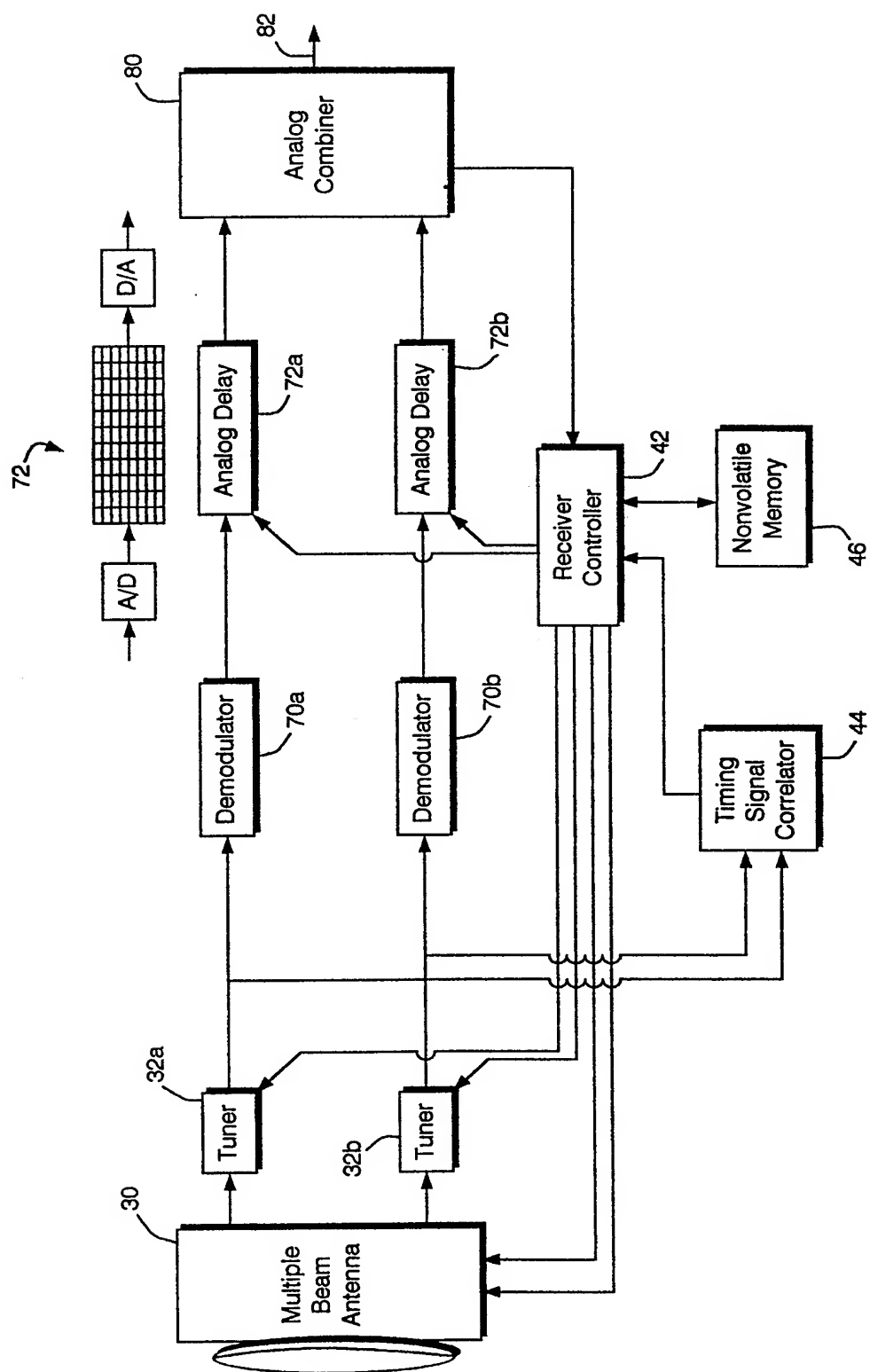
FIG. 1
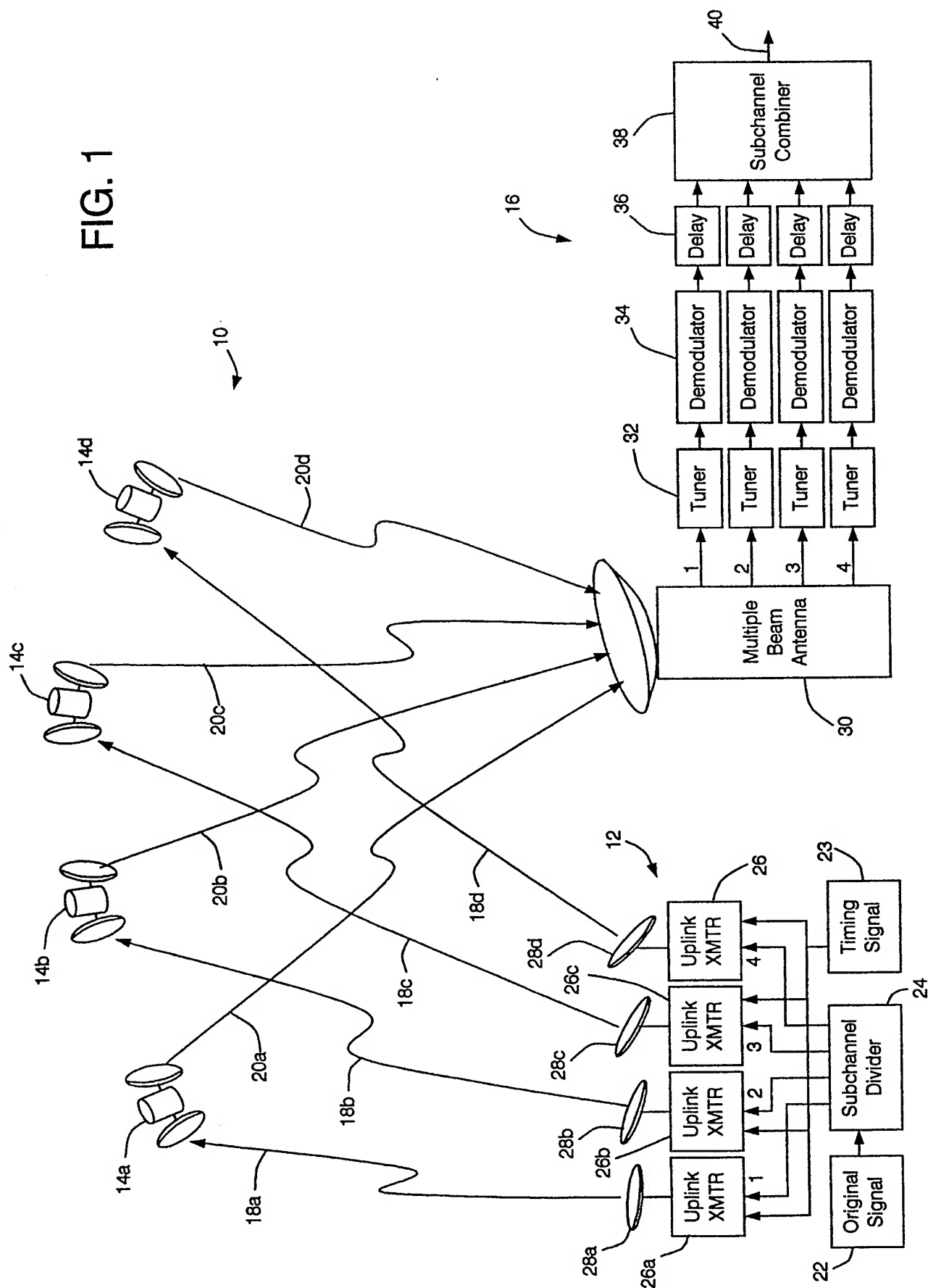
FIG. 2

FIG. 3

FIG. 4

International application No.

PCT/US99/02333

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 7/185
US CL : 455/13.1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/13.1, 12.1, 13.2, 13.3, 502, 132, 137

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WEST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,625,876 A (GILHOUSEN et al) 29 April 1997, see fig 2	1-35
A, P	US 5,745,839 A (LIEBERMAN) 28 April 1998, see column 3, line 25 through column 4, line 16	1-35
A, P	US 5,720,039 A (LIEBERMAN) 17 Febuary 1998, see all	1-35
A, P	US 5,790,939 A (MALCOLM et al) 04 August 1998, see column 2 line 5 throgh column 3, line 34	1-35
A	US 5,410,731 A (ROUFFET et al.) 25 April 1995, see all	1-35

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:
"A"	document defining the general state of the art which is not considered to be of particular relevance
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"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed

"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 MAY 1999	15 JUN 1999

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Form PCT/ISA/210 (second sheet)(July 1992)*

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A, P	US 5,867,109 A (WIEDEMAN) 02 Febuary 1999, see all	1-35
A, P	US 5,758,261 A (WIEDEMAN) 26 May 1998, see all	1-35